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AUTHOR Brannstrom, Lauritz
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ABSTRACT

Visual acuity as a function of target position and density was measured in a letter recognition task. A homogeneous pattern of equally-spaced elements was tachistoscopically exposed, where the target was never located at the boundaries of the pattern. The target was marked with a spatial cue to control attentional processes. With such a spatial arrangement, acuity should decrease with the increased distance of the acuity of the target from the fovea. The experiment involved the presentation of multi-letter displays varying in density, using a two-channel tachistoscope. The subjects' task was to identify an encircled target letter whose spatial position was varied across the displays. By controlling the subjects' attention and positional preferences and by avoiding end-effects for the dense displays, it was shown that acuity declined linearly with target distance for the densities 0, 5, and 10 elements per square degree. Density affected the acuity function's slope by making it steeper, while increasing density from 5 to 10 elements did not affect the slope further, suggesting that density only affects general visual load. Confidence ratings collected in the same experiment confirmed the recognition data. This report includes 12 references. (Author)

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EFFECTS OF SPATIAL POSITION AND DENSITY ON VISUAL ACUITY

by

Lauritz Brannstrom

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Department of Psychology
University of Umea

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EFFECTS OF SPATIAL POSITION AND DENSITY ON VISUAL ACUITY

Brännström, L. Effects of spatial position and density on visual acuity. Umeå Psychological Reports, No. 153, 1980 - Visual acuity as a function of target position and density was measured in a letter recognition task. By controlling the subject's attention and positional preferences and by avoiding end-effects for the dense displays it was shown that acuity fell off linearly with target distance for the densities 0, 5, and 10 elements per square degree. Density affected the slope of the acuity function by making it steeper while increasing density from 5 to 10 elements/square degree did not affect the slope further, suggesting that density only affects general visual load. Confidence ratings collected in the same experiment confirmed the recognition data.

Visual acuity falls off rapidly with the increase of distance to the fovea (or line of sight). Even at less than one degree of visual angle from the line of sight the acuity will be far from perfect (Alpern, 1962; Sloan, 1968). The measurement of acuity often rests on the presentation of a single object against a homogenous background, for example a Landolt C. If acuity is measured with a single letter, approximately the same results will be obtained as with a Landolt C (Bouma, 1978). The acuity function will also be affected by the number of elements simultaneously presented. With letter stimuli, Bouma (1970) found a more rapid decrement in recognition scores when noise letters were added. The lateral interferences caused by spatial proximity among elements is a well-established fact (Eriksen & Rohrbaugh, 1970; Flom, Weymouth & Kahneman, 1963; Strangert & Brännström, 1975). Thus, the distance of the acuity target to foveal vision, the number of noise elements and the spatial proximity of noise elements to the target element will affect acuity negatively.

With multi-element displays, end-elements will often be reported more accurately than elements closer to the line of sight (e.g. Brännström, 1973; Bouma, 1978; Mackworth, 1965). Using a detection task, Brännström (1980) noted that end-effects seemed to occur even when a nonredundant (random) spatial configuration of elements was presented. It is uncertain whether the observed end-effects could be attributed to the smaller lateral interferences of end-elements or to attentional processes. However, in order to get as pure estimates of acuity as possible for element positions within multi-element displays, end-effects should be brought under control. Thus the primary aim of the experiment was to measure acuity uncontaminated by end-effects. To achieve that, a homogenous pattern of equally spaced elements was tachistoscopically exposed where the target was never located at the boundaries of the pattern. Further, the target was marked with a spatial cue in order to control attentional processes. With such a spatial arrangement acuity should decrease with the increased distance of the acuity target from the fovea. Visual load should also affect acuity and another aim was therefore to measure acuity when the density of noise elements was varied. Increased density should make the acuity function more steep and move the recognition threshold closer to the fovea.

Method

The present experiment involved the tachistoscopic presentation of multi-letter displays varying in density. The subject's task was to identify an encircled target letter whose spatial position was varied across the displays.

Stimulus material

A stimulus display consisted of one of the target letters c or x together with 0, 119 or 238 equally spaced noise letters (m n r s v w and z). The total binocularly visible area with elements was 4.88° x 4.88° (23.81 square degrees). Thus densities were 0, 5, and 10 letters/square degree (see Drury & Clement, 1978). The central position was empty except for the fixation cross. The horizontal and vertical distances between the center of two adjacent letters were .49° for D=5 and .32° for D=10.

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The target letter could be located at any of the eight directions radiating in equal angles of 45^{o} with the upper vertical center line (0^{o}) as a reference. The distance between the center of the fixation cross and the target letter was varied in four steps. For D=0 and D=5 this resulted in the following visual angles with a viewing distance of .75 m: Horisontal and vertical directions - $.49^{o}$, $.97^{o}$, 1.46^{o} and 1.95^{o}; diagonal directions - $.69^{o}$, 1.37^{o}, 2.06^{o} and 2.75^{o}. For D=10 the corresponding visual angles were $.32^{o}$, $.65^{o}$, 1.29^{o} and 1.95^{o} and $.46^{o}$, $.92^{o}$, 1.83^{o} and 2.75^{o}, respectively. Thus, on the average, target positions were somewhat closer to the fixation cross for D=10. With eight directions and four target positions for each direction, the target could occupy 32 different locations. In practice, each target occured 16 times per density which resulted in a total of 96 different stimulus displays. The occurence of c and x was distributed equally over target positions so that each occurred twice per direction and equally often at each position (across directions).

For the dense displays, the noise letters occurred equally often. A fixed order of elements in a row was used. However, the first letter of each row was randomly determined for each stimulus display; the only restriction was that the same letter never could be the first letter in two consecutive rows. There were also letters outside even the most extreme target positions (at 2.75^{o}) for D=5 and D=10. By this arrangement end-effects were avoided.

The black letters were printed on an electric IBM typewriter with an ARTISAN 12 typehead. The target letter was always (even for D=0) surrounded by a black circle with an outer diameter of $.38^{o}$ and a thickness of $.02^{o}$ (MECA NORMA S.14). The nearest distance between the circle and the target was $.09^{o}$.

Procedure

A two-channel tachistoscope was used to present the following sequence of visual events to the subject on each trial: First, a faint fixation cross was presented at the center of the visual field for 800 msec. Secondly, at the offset of the fixation cross a stimulus display was exposed for 100 msec. The luminance levels were: General illumination of the room = 47 mL, background luminance of the display field before the exposures = 0 mL, luminance of the field with the fixation cross = 26.7 mL and luminance of the stimulus display field = 44 mL.

Before the experiment subjects were allowed 5 minutes for visual adaption. Then they were given 8 practice trials immediately followed by the 96 experimental trials. The presentation order of the stimulus displays was randomized for each subject. The time between each trial was determined by the subject who used a push-button to initiate a stimulus exposure. Normally an experimental session lasted 40 minutes. Each subject participated in two experimental sessions on two concecutive days.

The subject's task was to report whether a c or an x had been present in the stimulus display. He then made a confidence rating on a 10-graded scale where 0 meant "pure guess" and 10 "absolutely sure". Subjects were informed that the target letter could occur in any of the eight possible directions and at different distances from the fixation cross. In addition, they were told that c and x were equally frequent and that the order of density, spatial position and target letter was random.

Subjects

Five females and five males in the ages of 20-40 years served as voluntary subject. All subjects had normal vision on both eyes.

Results

The common differences between hemifields were not observed in the present experiment. The possibility of a left-right or an up-down difference in mean correct recognitions and ratings was tested by means of multiple regression analyses. None of these factors, nor their interaction term, contributed significantly ($p=.51$) and they explained less than 1 per cent of the variance of the recognition or rating scores. The spatial distance of the target letter accounted for practically all of the explained variance. The effect was highly significant ($p < .001$) for all densities in both rating and recognition.

Since there were no directional tendencies the data for the eight directions of target occurence were collapsed and mean proportion correct recognitions and mean rating scores were computed. For D=5 the outmost position in the upper right, lower right, lower left and upper left directions had to be excluded from the analysis because of technical fallacies at the stimulus presentation. In Figure 1 the mean proportion of correct recognitions is shown as a function of target position (in degrees of visual angle) for the different densities. The linear functions fitted to data do not include mean proportions greater than .97 or smaller than .53 since these values may be biased by "ceiling and floor effects", respectively.

For D=0 the linear acuity function was $\bar{Y}_p = 1.12 - .241d$ for $.50^{\circ} \leq d \leq 2.57^{\circ}$ and where $\bar{Y}_p$ is the mean proportion correct recognitions and d is the target distance in degrees of visual angle. With D=5 the function was $\bar{Y}_p = 1.15 - .295d$ for $.51^{\circ} \leq d \leq 2.20^{\circ}$ and with D=10 it was $\bar{Y}_p = 1.08 - .259d$ for $.31^{\circ} \leq d \leq 2.24^{\circ}$. The linear trend accounted for 95.8, 97.0 and 77.4 per cent of the observed variance in mean recognition scores when the density was 0,5 and 10, respectively.

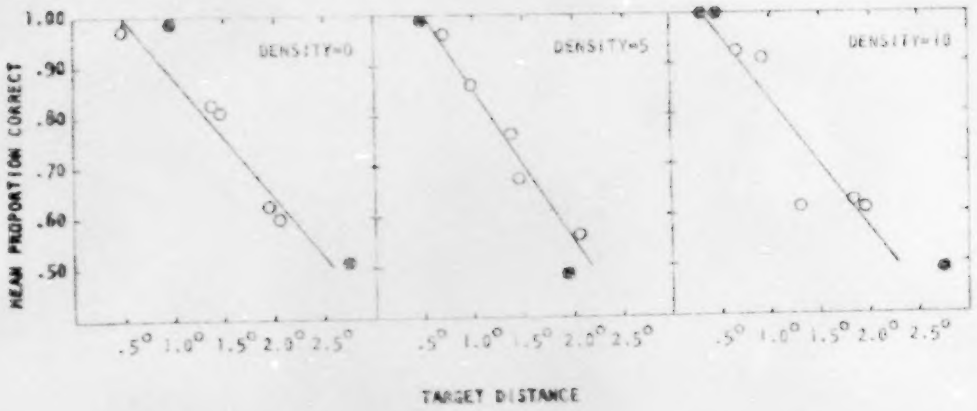

Figure 1. Mean proportion of correct recognitions as a function of target distance for the three densitites. The linear functions do not include p-values greater than .97 or smaller than .53 (filled circles).

The obtained acuity functions for D=5 and D=10 are evidently free from end-effects. The drop in acuity is quite rapid for all densities. When the target position exceeds about half a degree of visual angle, acuity begins to fall off and a random recognition level ($\bar{p}$ = .50) occurs at about 2.5 degrees. The clear difference in slope between D=0 and D=5 should be attributed to a general increase in visual load rather than to lateral interferences of surrounding noise elements. For D=10 the slope is, unexpectedly, smaller than for D=5. One reason for that is the deviating mean score for D=10 at d=1.29°. No reasonable explanation of that deviation can be given.

In Figure 2 the mean rating scores for correct responses are presented as a function of target distance for the three densities. A mean rating score was excluded in the linear regression analyses when the corresponding mean proportion of correct recognitions was greater than .97 or smaller than .53.

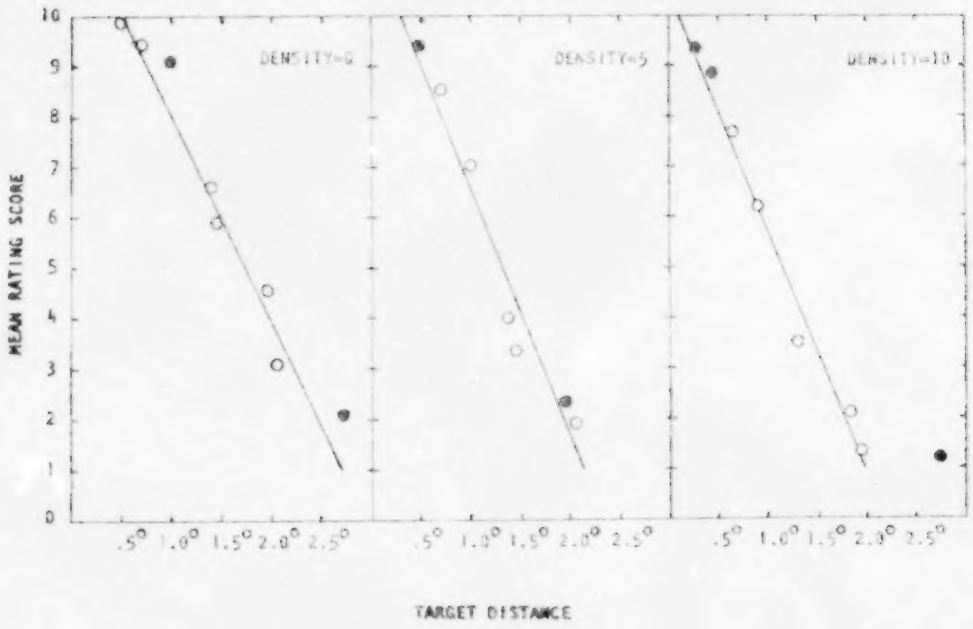

Figure 2. Mean rating scores for correct responses as a function of target distance for the three densities. Mean scores not included in the fit of linear functions are marked with filled circles.

The linear function for D=0 was $\bar{Y}_R = 12.12 - 4.142d$ for $.51^\circ \leq d \leq 2.93^\circ$, where $\bar{Y}_R$ is the mean rating score for correct answers and d is the target distance in degrees of visual angle. With D=5 the function was $\bar{Y}_R = 11.59 - 5.052d$ for $.31^\circ \leq d \leq 2.29^\circ$ and with D=10 it was $\bar{Y}_R = 10.49 - 4.745d$ for $.10^\circ \leq d \leq 2.21^\circ$. The linear trend accounted for 97.8, 93.1 and 96.8 per cent of the observed variance in mean rating scores when the density was 0,5 and 10, respectively.

The linear functions for the mean ratings corroborate those obtained for the mean recognitions. There are clear differences between the rating functions due to the density factor. The slope for D=0 is much smaller than the slopes for D=5 and D=10. The difference in slope between D=5 and D=10 is, however, negligible. The intercept of the functions decreases with increased density. Probably this can be due partly to different frames of reference in the rating

scales. However, the correspondence between recognition and rating data is quite good, a fact demonstrated in Figure 3 where the mean proportion of correct recognitions are plotted against the mean rating scores.

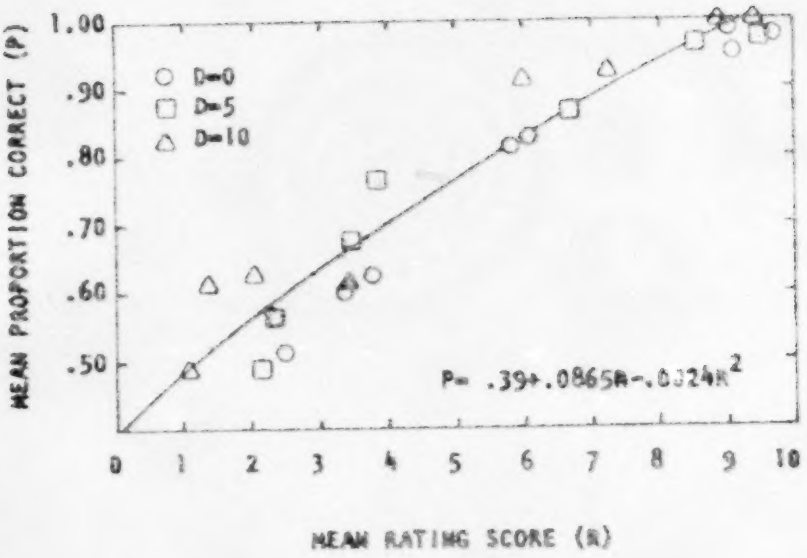

Figure 3. Mean proportion of correct recognitions plotted against mean ratings. The function is based on all data.

The linear and quadratic trends accounted for 93.0 per cent of the variance (linear trend = 92.4 per cent; quadratic trend = .6 per cent). Thus, it can be concluded that both the recognition and the rating method are similarly affected by the manipulations of the spatial position of the target letter.

Discussion

The present experiment shows that it is possible to measure acuity uncontaminated with end-effects within multi-element displays. The use of a homogenous pattern of equally spaced noise elements with the acuity target never located at the boundaries of the pattern

is an effective technique for controlling end-effects. The systematic spatial layout and the use of a spatial marker seems to have brought positional preferences under control and directed the subject's attention properly to the target location. The multiple regression analyses of both recognition and rating data did not reveal any directional tendencies. The linear trend in the acuity functions was very strong (see Figure 1).

Acuity was less than perfect as soon as the target distance exceeded about half a degree of visual angle (cf. Alpern, 1962; Sloan, 1968). Estimating the size of the functional field of view from the obtained acuity functions (i.e. when $\bar{p}$ reaches .50) yielded the following for recognition data: For D=0 it was 5.2° and for D=5 and D=10 it was 4.4° around the line of sight. Since the similarity of functions for the recognition and rating data is substantial, similar estimates of the functional field of view should be obtained for the rating data. Using the point of the rating functions where subjects should rate "0" (i.e. pure guess) as the limit of the functional field yielded for D=0 a field of 5.9°; for D=5 and D=10 it was 4.6° and 4.4°, respectively. Thus, the functional fields estimated from the rating data differ only slightly from those obtained from the recognition data. The correspondence between the estimates based on rating and recognition data is confirmed by the good correspondence between the recognition and rating data (Figure 3).

Density seems to affect the acuity functions only moderately by making the fall off somewhat faster in comparison to D=0. When density was increased from D=5 to D=10 no further effect of the factor was observed. Thus, the effect of density on the acuity functions seems to reflect an increase in general visual load, an effect that appears to be at an asymptotic level already at D=5. The small differences in size of the functional fields for the different densities support such an interpretation.

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